

MAPPING CORAL REEF HABITAT OF SOUTH ANDAMAN: A COMPARATIVE ANALYSIS OF DIFFERENT MULTI-SPECTRAL DATA SETS

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ABSTRACT:

Coral reefs are considered one of the most diverse, productive and sensitive ecosystems among the various ecosystems existing today. They are usually found in clear waters and often amenable to optical remote sensing. But the submerged and heterogeneous coral reef habitats, the intervening atmospheric path radiance, the contribution of water surface and the effects of variation in water column depth pose great challenge in processing of the measured signal. The present study involves the mapping of coral reefs at certain selected islands of Mahatma Gandhi Marine National Park, South Andaman using multi-spectral data sets of varying resolution and a comparative analysis. Three main aspects considered in the study are spatial resolution, spectral resolution and reef system configuration. Data sets used in the study are IRS P6 AWiFs, IRS P6 LISS 3, Landsat ETM and IKONOS multi-spectral data that represents a range of spatial and spectral resolutions. As this exercise involves a multi-sensor multi-resolution approach, the water leaving reflectance signal were isolated from the influence of atmospheric effects and the same image classification procedure had been adopted for all the data sets. The overall classification accuracy obtained for IKONOS MSS and LANDSAT ETM reveals that blue band (0.45 μ m-0.53 μ m) can contribute greatly to the accuracy of digital classification with respect to coral reef mapping. Depth invariant bands developed from suitable pairs of visible bands helped in discerning six classes of reef habitat from IKONOS MSS. Further analysis with respect to accuracy by taking more reference points falling on the edges or confluence zones of classes from Quick Bird data set is in progress.

1. INTRODUCTION

Coral reefs are known for their biodiversity, ecological complexity, and net primary production. They are usually found in relatively shallow waters, exposed to direct sunlight with an optimum temperature of 23°C-25°C and free from suspended sediments. They serve as natural protection against shoreline erosion and storm damage and harbour a variety of organisms. But in recent years a decline and degradation in coral reef habitat is noticed in many parts of the world. This is considered as a response to change in physical and biological characteristics of its environment caused by natural or anthropogenic factors. A continuous and effective monitoring of its extent and content is essential to understand the inherent coral reef processes and to establish conservation measures.

As coral reefs are usually found in clear waters, they are amenable to remote sensing techniques. But most of the sensors are able to provide information only on reef geomorphology or limited ecological information. Remote sensing based mapping of coral reefs is confronted with three major difficulties. Firstly, the water column on coral reefs strongly absorbs longer wavelengths, thus the use of electro magnetic radiations is limited to visible regions (450-650nm). The intervening above water atmospheric path, the contribution of water surface and water column depth variation effects also pose great challenge to the processing of the measured reflectance. Secondly, because of their symbiotic

association with zooxanthelle, discrimination of corals from algae merely based on the spectral signatures is difficult especially with data sets of broad spectral resolution. Thirdly corals are highly heterogeneous, the spatial resolution of currently available and widely used satellites is considered too coarse to map reef features in detail as spectral mixing occurs within a pixel (Nadoka et al., 2002).

Studies evaluating the performances of various satellites are already available but almost all of them are limited to shallow reefs and atolls. The performances of LANDSAT – 7 ETM+, ASTER, SPOT HRV, IKONOS satellite sensors and the airborne MASTER (MODIS – ASTER simulator) were evaluated for coral reef habitat mapping in South Pacific reefs (Capolsini et al., 2003). Mumby et al. (2002) have estimated the cost and accuracy of using IKONOS imagery to map shallow-water marine environment and compared directly to that of using a suite of satellite and airborne instruments including Landsat Multispectral Scanner (MSS) and LANDSAT-TM, SPOT-High Resolution Visible multispectral and panchromatic and Compact Airborne Spectrographic Imager (CASI). They have suggested that IKONOS may only be cost effective option only if independent field data are available to identify habitat patches, the area to be mapped is very small and small scale habitat dynamics are to be monitored. IKONOS data are unlikely to identify deterioration in coral reefs directly because changes in community structure

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cannot be resolved spectrally from the satellite. Influence of the spatial resolution of SeaWiFS, LANDSAT-ETM &, SPOT, and International Space Station data on estimates of landscape parameters of Pacific Ocean atolls have been studied by Andrefouet et al. (2003). Nayak et.al. (2003) have carried out the ecomorphological zonation of major coral reefs in India using IRS 1C/1D LISS 3/PAN data.

The present study looks into the potential of different multispectral data sets that represents a range of spatial and spectral resolutions in discerning the units in a reef habitat of much diversity. This may help a potential user in easy and optimal selection of data set depending on the purpose at hand.

METHOD

2.1 Study Area

Mahatma Gandhi Marine National Park, the first marine protected area in India is located at Wandoor, 30kms from Port Blair, Andaman and Nicobar. It was established in the year 1983 with a view to protect and conserve its rich coral biodiversity. Red Skin, Hobday and Jolly Buoy Islands falling within 92° 34' 52'' E - 92°37' 16'' E longitude and 11° 29'43'' N - 11° 34' 54'' N latitude of MGNP were selected for the study as these islands are surrounded by luxuriant growth of corals and comparative analysis among different data sets was limited to Jolly Buoy Island. The study area comprises of typical fringing reefs and patchy coral reefs and are known to occur down to a depth of 35 meters.

2.2 Data Used

IKONOS MSS and Panchromatic data of 4m and 1m spatial resolution respectively, were taken as the key data set. Other data sets used in the study include IRS- P6 AWIFS (56m), IRS P6 LISS 3 (23.5m), and LANDSAT- ETM (30m). The resolution characteristics pertaining to each of these satellite data are given in APPENDIX A.

2.3 Digital data Processing

Georeferenced IKONOS PAN image of 1m spatial resolution acquired on 12 February 2005 was taken as the key data. All other digital data sets were georeferenced and projected to UTM WGS 84 with respect to the key data set, IKONOS PAN. As the study involves the comparison of spectra of various reef units among different data sets, the digital values were converted to spectral radiance ($Wm^{-2}sr^{-1}\mu m^{-1}$) based on the equations and calibration coefficients obtained from sensor calibration details available in the metadata. Prior to atmospheric and water column correction, the landmass in the study area is masked out from the water body. Blue band (450-520nm) can penetrate through water body upto ~30m but red band (630 – 690nm) attenuates rapidly in water and only can penetrate upto ~5m whereas infra red gets almost totally absorbed. Mean value of spectral radiance of selected pixels of deep water were calculated for infra red and red bands, and the trend observed in these is extrapolated to derive the path radiance for green and blue band. The path radiance thus obtained for each band is subtracted from the respective bands to isolate the profiles of prominent reef unit viz., living coral zone and non aligned coral zone and its confluence point with other classes

atmospheric effects. The corals in the study area are of non emergent type and are usually found beyond a depth of one meter or more and the habitat type is almost similar to each other. Hence to account for the effect of varying depth of water column, depth invariant bands were created using the method of Lyzenga (1981). As the study area depicts clear water conditions, this method is adopted. In relatively clear water, the intensity of light will decay exponentially with increasing depth. If values of radiance were transformed using natural logarithms (ln), the relationship between depth and radiance will become linear. The method assumes that the bottom reflected radiance is approximately a linear function of the water depth (Lyzenga, 1981). Depth invariant bottom index is created from a pair of suitable spectral bands.

$$\text{Depth-Invariant Index } L_{ij} = \ln(L_i) - [(k_i/k_j) \cdot \ln(L_j)] \quad (1)$$

Where L_i and L_j = the atmospherically corrected radiance for bands i and j
 k_i/k_j = the ratio of attenuation coefficients

Attenuation coefficient is the gradient of the line obtained from the plot of transformed band i against transformed band j for a unique substratum. Ratio of attenuation coefficient is developed from pixels of sand at varying depths. Composites of depth invariant index were created with respective data sets. Also composites consisting of depth invariant index and atmospherically corrected radiance spectral bands were developed. The composites were subjected to digital classification. Iterative Self Organizing Data Analysis (ISODATA) is selected as the classification algorithm for the present study. ISODATA starts with all pixels as a member of spectral class no. 1. The ISODATA procedure then creates less variable spectral class from the variable initial spectral class. As there is very high chance of spectral merging, hundred initial spectral classes were specified with a convergence threshold of 0.99 within twenty iterations. The visual interpretation of PAN sharpened IKONOS resulted in three major reef units viz., windward reef front, outer living coral zone of the outer reef crest, non-aligned coral zone and sanded reef flat.

Windward reef front include reef slope, marginal channels, terraces, reef front/fore reef, spur and groove systems and is the highest energy zone of the reef. This region has high coral growth of about 50% in the first 5m. Below 15m the coral cover gets restricted but diversity increases (Hopley, 1982). Living coral zone is also found on outer reef crest adjacent to windward reef front. On reef tops normally receiving lower wave energy the reef flat may be formed from randomly scattered ovoid coral conies with intervening sand patches. This termed as non aligned coral zone (Hopley, 1982). Most of the Indian reefs have NACZ (Nayak et.al, 2003). Sanded reef flat is formed towards the lee side by the deposition of sand. The sand is mainly coralline in nature, consisting of fine sand and broken molluscan shells (Fairbridge, 1968).

The spectral classes obtained through ISODATA classification algorithm were grouped into categories viz., deep water, outer living coral zone, non-aligned coral zone, and sanded reef flat based on cursor enquiry on IKONOS PAN sharpened image which is the key data set and sea truth information. Spectral were also taken into account while recoding. In similar situation Malthus et al. (2003) integrated field and high spatial resolution

satellite data for monitoring shallow submerged aquatic habitats in the Sound of Eriskay, Scotland. In fact in order to get pure coral zone, wherever mixing of coral zone with other classes occurred, that spectral class was attributed to the category that represents spatial majority.

Accuracy of the classification is quantified by comparing the classification to geographical data that are assumed to be true by an error or contingency matrix. Usually, the assumed true data are derived from the ground truth data. In this case it was not practical to sea truth or otherwise to test every pixel of a classified image. The error matrix must be representative of the entire area mapped from the remotely sensed data (Congalton, 1991). Therefore, a set of reference pixels collected through sea truth and another set from pan sharpened IKONOS image that were randomly selected were used as reference pixels. Overall accuracy and Kappa statistics were obtained from contingency matrix. Also area statistics were computed for all the classes for comparison among different data sets.

2.4 Results and Discussion

The spectral profile of various features in the reef habitat of IKONOS MSS data depicts that there is clear distinction between prominent classes i.e., coral reef flat, coral zone and non aligned coral zone (APPENDIX B). Digital classification of the IKONOS composite produced from depth invariant index of blue and green bands and atmospherically corrected radiance spectral bands of blue and green could effectively delineate various reef units viz., living coral zone of windward reef front and outer reef crest, terraces, non aligned coral zone and sanded reef flat (Figure 1). The overall classification accuracy obtained for IKONOS MSS is 86.00% and overall Kappa statistics is 0.82 which is highest among the data sets considered (Table 1). The 11bit radiometric resolution of IKONOS also might have added to the increased accuracy. Similar band combinations were considered for classification of Landsat ETM with a spatial resolution of 30m. The overall classification accuracy obtained is 54.00 % with an overall kappa statistics of 0.42. Both IRS P6 LISS 3 and AWIFS recorded overall classification accuracy of only 48 % and 36% respectively. Area statistics obtained for various reef units reveals that spectral aggregation of reef features occurs as the spatial resolution becomes coarser (Figure 2). IKONOS MSS recorded a total of 21.82 hectares of live coral zone located at windward reef front and outer reef crest zones whereas AWIFS could delineate only 9 hectares. Non aligned coral Zone and live coral zone together comprises 55.44 hectares from AWIFS and is almost tallying with that of IKONOS and LANDSAT ETM which recorded 55.46 hectares and 52.87 hectares respectively. Though points were taken randomly for generating error matrix, the results of the present study reveal that more reference points should be taken in the transition region or edges between two classes so that classification accuracy can be studied more effectively. Exercise in this direction is progressing.

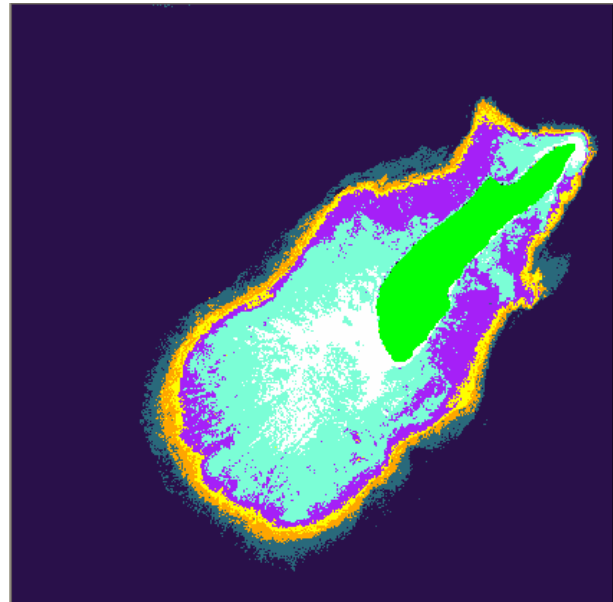
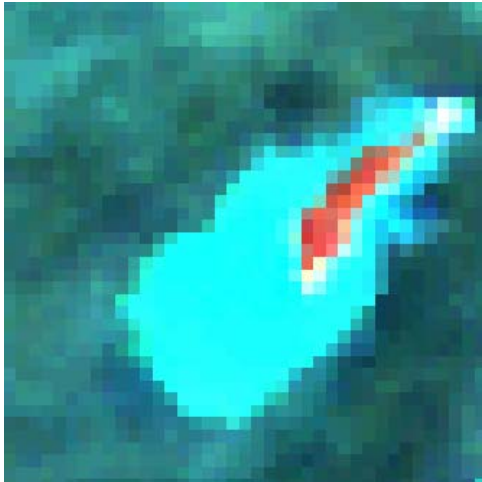


Figure 1 Jolly Buoy Island – Classified image of Depth Invariant Bands developed from IKONOS MSS

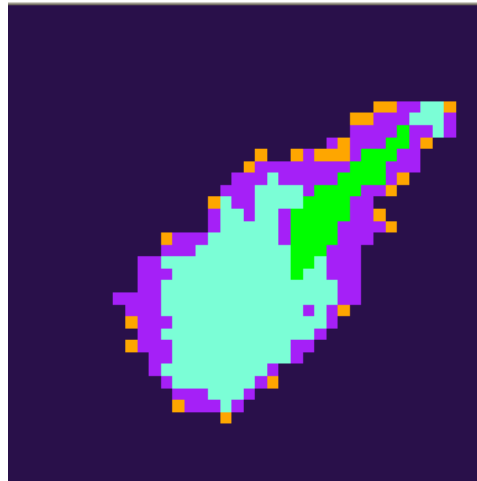
LEGEND

- REEF FLAT - MAINLY SAND
- REEF FLAT - SAND, BOULDERS & OTHER DEBRIS
- NON ALIGNED CORAL ZONE
- LIVE CORALS OF THE OUTER CREST ZONE
- LIVE CORALS OF THE WINDWARD REEF ZONE
- TERRACE
- DEEP SEA

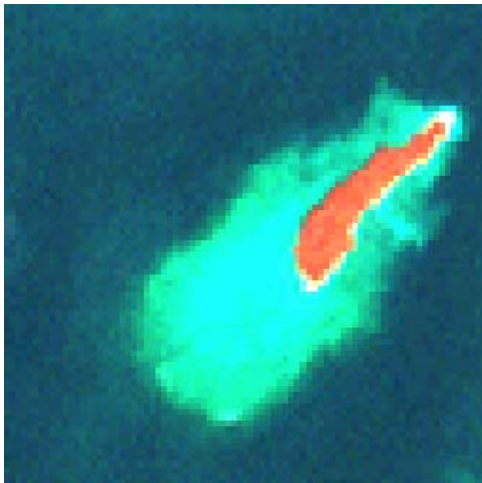
Figure 2. False Colour Composites and Classified Images of Coral Reef Habitat - Jolly Buoy Island



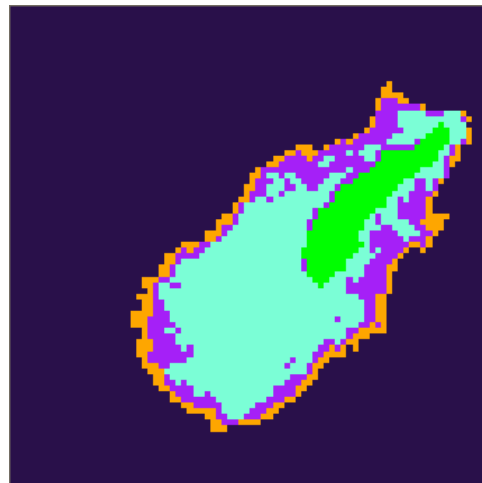
IRS P6 AWIFS FCC



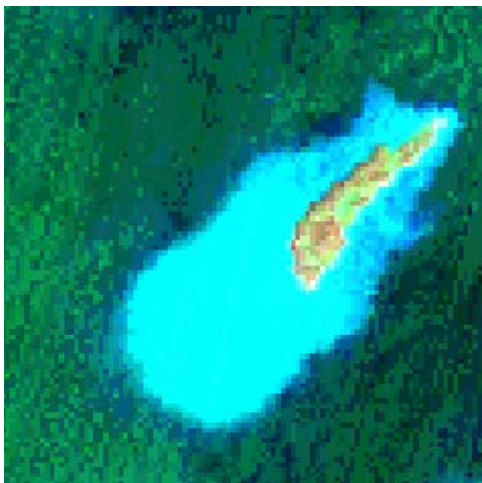
CLASSIFIED OUTPUT- IRS P6 AWIFS



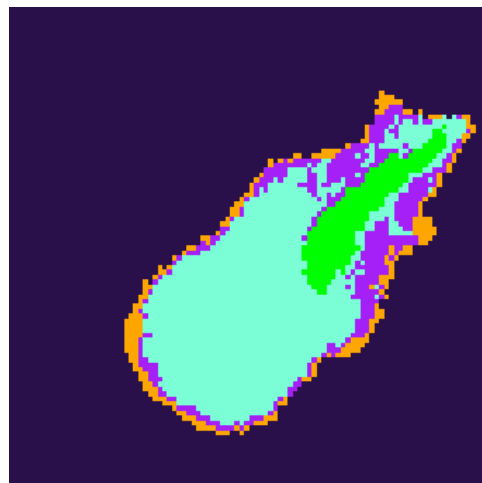
LANDSAT ETM FCC



CLASSIFIED OUTPUT- LANDSAT ETM



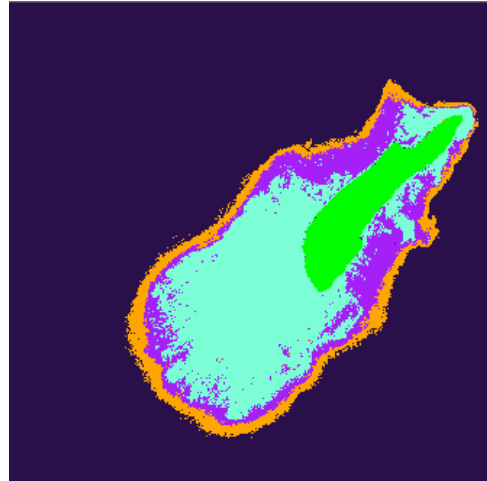
IRS P6 LISS 3 FCC



CLASSIFIED OUTPUT- IRS P6 LISS 3



IKONOS MSS FCC



CLASSIFIED OUTPUT- IKONOS MSS

LEGEND

- LANDMASS
- SANDED REEF FLAT
- NON ALIGNED CORAL ZONE
- LIVE CORALS ON WINDWARD REEF FRONT & OUTER REEF CREST
- DEEP SEA

Table 1. Area Statistics and Overall Accuracy obtained for classified Images from different sensors

SL.NO	DATA SETS	LAYERS IN THE COMPOSITE	OVERALL CLASSIFICATION ACCURACY (%)	OVERALL KAPPA STATISTICS	AREA STATISTICS (HECTARES)			
					LIVE CORAL ZONE	NON ALIGNED CORAL ZONE	SANDED REEF FLAT	DEEP WATER
1	IKONOS (4m)	DEPTH INVARIANT INDEX (BLUE-GREEN), CORRECTED RADIANCE IMAGES BLUE&GREEN)	86.00	0.82	21.82	33.64	74.27	398.98
2	IRS P6 LISSIII (23.5m)	DEPTH INVARIANT INDEX (GREEN-RED), CORRECTED RADIANCE IMAGES (GREEN & RED)	48.00	0.35	15.09	26.72	89.28	434.36
3	LANDSAT ETM (30m)	DEPTH INVARIANT INDEX (BRUE-GREEN), CORRECTED RADIANCE IMAGES (BLUE & GREEN)	54.00	0.42	18.19	34.68	80.41	421.80
4	IRS P6 AWIFS (56m)	DEPTH INVARIANT INDEX (BRUE-GREEN), CORRECTED RADIANCE IMAGES (BLUE & GREEN)	36.00	0.19	9.00	46.44	61.92	444.24

3. CONCLUSION AND FUTURE DIRECTIONS

The overall classification accuracy obtained for IKONOS MSS and LANDSAT ETM reveals that blue band (0.45 μ m-0.53 μ m) can contribute to the increased accuracy of digital classification with respect to coral reef mapping. Depth invariant bands developed from suitable pairs of visible bands helped in discerning six classes of reef habitat. High resolution satellites like IKONOS MSS with a radiometric resolution of 11 bits can contribute to a considerable extent in capturing the heterogeneity within the geomorphological units of coral reef. LANDSAT ETM data along with sufficient sea truth information offers a good choice if more intricate classification is not needed and cost is a constrain.

The initial findings of the study only are presented here. High resolution Quick Bird data set is also under processing and further analysis is continuing.

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APPENDIX A. RESOLUTION DETAILS OF SATELLITE DATA SETS USED IN THE STUDY

NAME OF SENSOR	DATE OF PASS	SPATIAL RESOLUTION	SPECTRAL RESOLUTION	RADIOMETRIC RESOLUTION
IKONOS PAN IKONOS MSS	12 FEB 2005	1 meter 4 meters	0.45 - 0.90µm 0.45 - 0.53 µm (blue) 0.52 - 0.61µm (green) 0.64 - 0.72µm (red) 0.77 - 0.88µm (near IR)	11 bits
IRS P6 LISS III	11 FEB 2005	23..5 metres	0.52 - 0.59 µm (green) 0.62 - 0.68µm (red) 0.77 - 0.86µm (near IR)	8 bits
LANDSAT ETM	07 FEB 2000	30 meters	0.45 - 0.515µm(blue) 0.52 - 0.60µm (green) 0.63 - 0.69 µm (red) 0.75 - 0.90µm (near IR)	8 bits
IRS P6 AWIFS	08 JAN 2005	56 meters	0.52-0.59 µm (green) 0.62-0.68 µm (red) 0.77-0.86 µm (near IR)	11bits

APPENDIX B. SPECTRAL OF CORAL HABITAT UNITS – IKONOS MSS

